

# LIQUID ADDITIVE SLOW-RELEASE APPARATUS DRIVEN BY A FILTER PRESSURE GRADIENT

## 5 BACKGROUND OF THE INVENTION

The present invention is directed to a liquid filtration system and to a method of treating the liquid in the enclosed system.

Filter assemblies are commonly used to protect combustion engines by filtering out contaminants and thereby preventing damage to the engine and other downstream components such as valves, fuel injectors, fuel lines, and related other components. To maintain engine  
10 performance and reliability, the filter assemblies must be replaced, often as frequently as every 2,000 to 4,000 vehicle miles.

It can be equally important to add agents to the fuel to reduce damage to the engine and related downstream components and/or to enhance the performance of the engine. For example, since the early 1990's diesel fuel producers have significantly reduced the sulfur content in diesel  
15 fuel to reduce the environmental harm that was attributed to the burning of high sulfur content fuels. However, the naturally occurring sulfur in the diesel fuel also acted as a lubricant. The resulting low sulfur content diesel fuel caused increased wear on the diesel engine and, in particular, to the fuel pump and injectors, which in turn caused significant harm to the overall operation, performance, and efficiency of the engine and even to the environment.  
20 Consequently, various additives were developed to increase not only the lubricity but also to enhance fuel stability, fuel combustion, and engine performance.

It is difficult to maintain a constant or desired level of the additive in the fuel. Typically an operator adds a bottled additive or additive concentrate to the vehicle fuel tank with each fuel  
25 fill-up. While many bottled fuel additives are commercially available, often operators do not consistently add the additive with each fill-up--the additive might not be readily available or the operator may forget to include the additive. Combining the additive with fuel in the fuel tank may not reliably provide a homogenous fuel/additive mixture.

Fuel tanks do not include reliable methods for mixing fuel. Generally operators rely  
30 upon the turbulence created during a fill-up and by vehicle motion to mix the additive and fuel. Furthermore, the additive concentration in the fuel may vary, depending upon the amount of fuel in the fuel tank--assuming a set amount of additive is added with each fill-up.

Various alternative methods have been developed to add the additives to fuel. One method includes providing a fuel additive in a filter assembly such as disclosed in U.S. Patent No. 6,238,554 issued to Martin et al., which adds the additive to the fuel under diffusion-controlled conditions.

5 Another method is disclosed by Davis in U.S. Patent No. 5,507,942, which includes a filter assembly with a solid fuel additive that dissolves in the fuel as the additive contacts the fuel in the filter assembly.

10 The present invention provides a novel method of treating fuel by capitalizing on the existence of or developing a fluid pressure gradient within the filter assembly. The pressure gradient can then be harnessed to continuously add the fuel additive to the fuel flowing through the filter assembly. Consequently, the present invention provides novel advancements and additionally provides a wide variety of benefits and advantages in the relevant subject matter.

15 While the above discussion has been directed toward filter assemblies, the present invention provides a novel filter assembly and method of treating the fluid flowing through that filter, regardless of whether that liquid is a fuel. The principles embodied in the present invention apply to filters in general and can be used in filter assemblies, air filters, lubricant filters, and/or coolant filters.

## BRIEF SUMMARY OF THE INVENTION

The present invention relates to a novel filter assembly, the manufacture and use thereof. Various aspects of the invention are novel, nonobvious, and provide various advantages. While the actual nature of the invention covered herein can only be determined with reference to the claims appended hereto, certain forms and features, which are characteristic of the preferred  
5 embodiments disclosed herein, are described briefly as follows.

In one form, the present invention provides a filter that comprises a housing defining an interior chamber and including an inlet, an outlet, and a fluid pathway for a liquid flowing through the interior chamber. Liquid flowing through the fluid pathway generates a pressure  
10 gradient within the interior chamber such that in a first region of the interior chamber, the flowing liquid exhibits a first (higher) fluid dynamic pressure and in a second region the flowing liquid exhibits a second (lower) fluid dynamic pressure. The filter also includes a filter element disposed in the interior chamber in the fluid pathway between the inlet and the outlet and a container disposed within the interior chamber. The container has an exterior wall that defines  
15 an interior region. The container also includes a first opening with a first capillary tube extending from the exterior wall and a second opening through the exterior wall and spaced apart from the first opening. The first opening and said second opening each provide fluid communication between the interior chamber and the interior region. A liquid additive can be deposited in the interior region. The liquid additive can be selected to provide a benefit to at  
20 least one of a fuel, oil, lubricant, and coolant.

In another form the present invention provides a filter that comprises a housing defining an interior chamber and including an inlet and an outlet into the interior chamber; and a filter element disposed in the interior chamber between the inlet and the outlet, where the filter element partitions the interior chamber into two regions--an entering region proximate to the  
25 inlet and an exiting region proximate to the outlet. The filter also includes a container disposed within the interior chamber and defining an interior region. The container has a first capillary tube extending into the entering region and a second capillary tube providing fluid communication between the interior region and the interior chamber. A liquid additive, which has been selected to provide a benefit to the liquid flowing through the filter, can be deposited in  
30 the interior region of the container.

The present invention also provides a method of supplying an additive to the liquid flowing through a filter assembly. The method comprises generating a dynamic fluid pressure gradient within the filter housing; providing an additive in a container within the filter housing; positioning an inlet port for the container proximate to an area of a first dynamic fluid pressure within the filter housing; and positioning an outlet port for the container proximate to an area of a second dynamic fluid pressure less than the first dynamic fluid pressure thereby inducing the liquid additive to flow out of the container.

Further objects, features, aspects, forms, advantages, and benefits shall become apparent from the description and drawings contained herein.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of one embodiment of a filter in accordance with the present invention.

FIG. 2 is an exploded cross-sectional view of a filter of the filter of FIG. 1.

FIG. 3 is a partial view in full section of the lower portion of the filter illustrated in FIG. 1.

FIG. 4 is a graph illustrating the dynamic pressure of a fluid flowing through a filter measured at varying axial position within the filter housing between the filter and shell.

FIG. 5 is a graph comparing the flowrate of a fluid entering a container with a capillary tube outlet to a container without a capillary tube outlet.

FIG. 6 is a graph comparing the flowrate of a liquid additive (the active ingredient portion of an increasingly dilute mixture) exiting a container with a capillary outlet to a container without a capillary outlet.

FIG. 7 is a partial view in full section of an alternative embodiment of a filter in accordance with the present invention.

FIG. 8 is a partial view with sections broken away of yet another alternative embodiment of a filter with a flow-directing insert in accordance with the present invention.

FIG. 9 is a sectional view taken along section line 9-9 of the flow-directing insert illustrated in FIG. 8.

FIG. 10 is a cross-section view of another embodiment of the filter in accordance with the present invention.

FIG. 11 is a sectional view taken along section line 11-11 of the additive cartridge illustrated in FIG. 10.

FIG. 12 is a perspective view of a replaceable cartridge for use in the present invention.

FIG. 13 is a cross-sectional view of the replaceable cartridge illustrated in FIG. 12.

FIG. 14 is an elevated view in full section of yet another embodiment of a filter with a replaceable cartridge in accordance with the present invention.

FIG. 15 is a cross-sectional view of still yet another embodiment of a filter with an extended shroud on the filter element endcap for enhanced liquid velocity at the inlet tube in accordance with the present invention.

FIG. 16 is a partial view of the extended shroud on the filter element endcap and inlet tube illustrated in FIG. 15.

## DETAILED DESCRIPTION OF THE INVENTION

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated herein, and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications of the described filters, cartridges, and processes, and any further applications of the principles of the invention as described herein, are contemplated as would normally occur to one skilled in the art to which the invention relates.

FIG. 1 is a cross-sectional view of a filter assembly 10 provided in accordance with the present invention. FIG. 2 is an exploded, cross-sectional view of the same filter assembly 10. Filter assembly 10 includes a housing or outer casing 12 defining an interior chamber 14. A nut plate 16 is secured across an open end 13 of casing 12. Nut plate 16 provides at least one inlet 18, preferably a plurality of inlets, and at least one outlet 20. In the illustrated embodiment, nut plate 16 includes a plurality of inlets 18 encircling a centrally-located outlet 20. Both inlet(s) 18 and outlet 20 provide fluid communication with interior chamber 14 to allow a liquid such as, and organic based fuel, lubricant, or oil fluid; or an aqueous based coolant, to flow into and out of interior chamber 14. Additionally, a filter element 22 and a vessel or container 24 and, optionally, biasing element 26, are provided in interior chamber 14.

Filter element 22 is positioned in a fluid pathway between the liquid entering through inlet 18 and exiting through outlet 20. Additionally, filter element 22 can partition interior chamber 14 into a liquid entering region 28 and a liquid exiting region 30. Filter element 22 is provided in the form of any known and commercially available filter material. Examples of a material that can be used as a filter element include paper (cellulose), cloth, polyester, wire mesh, plastic mesh, gradient density melt-blown polymeric materials, and the like. In the illustrated embodiment, filter element 22 is provided as a cylindrical sleeve formed of a pleated sheet of filter material. The cylindrical sleeve defines a centrally-located axis 23. On either end of the cylindrical sleeve, filter element 22 is supported within interior chamber 14 with a first and second filter endcaps 31 and 33 to provide a fluid-tight seal. Consequently, a liquid flowing through filter assembly 10 must pass through filter 22 to flow from entering region 28 to exiting region 30.

Filter assembly 10 also includes a drain valve 35 in outer casing 12. It will be understood that for some applications the filter assembly need not include a drain valve. However, when present, drain valve 35 can be used to drain out any water that has separated from a non-aqueous liquid such as the organic based fuels, oils, and lubricants. The separated water can collect in the bottom of the interior chamber 14. The water can flow down between the inside wall of casing 12 and the exterior wall of container 24, which can have vertically extending spacers 37 to separate and centrally position container 24 in the interior chamber 14.

Referring additionally to FIG. 3, which is a partial view in full section of the lower portion of filter assembly 10, container 24 is positioned inside interior chamber 14. A liquid additive 25 can be deposited in the interior chamber 14. In the illustrated embodiment, container 24 is disposed between the closed end 27 of outer casing 12 and the lower endcap 32 of filter element 22. Biasing element 26, which is illustrated as a circular spring, biases container 24 against the lower endcaps 32 of filter element 22, and, consequently, forces endcap 3 of filter element 22 against nut plate 16 or a seal disposed therebetween.

Container 24 includes an exterior wall 34. In the illustrated embodiment, exterior wall 34 includes a plurality of spacers 37 each configured as a small, axially-oriented rib. The spacers 37 provide a gap between the exterior wall 34 of container 24 and the interior wall of casing 12 so that separated water can fall down between the wall 34 where a drain valve 35 can be used to remove the accumulated water. Exterior wall 34 defines an interior region 40. In this embodiment, container 24 defines a cylindrical reservoir or depot concentric about axis 23. Container 24 can be provided as a two-piece (or more) structure(s), which pieces are interconnected via a connection. The connection can be a threaded connection sealed with adhesive, snap-fit, ultra-sonic welded, or spin-welded, as desired. In a preferred embodiment, container 24 will be provided as a two-piece structure with a spin-weld connection joining the two structures.

Entrance port 42 provides an opening through exterior wall 34. Similarly, exit port 44 also provides an opening through wall 34. Both entrance port 42 and exit port 44 provide a pathway for liquid in interior chamber 14 to enter and exit, respectively, interior region 40 of container 24.

In a preferred embodiment, entrance port 42 is provided as a small diameter tube or capillary tube 48. In a particularly preferred embodiment, capillary tube 48 has a desired length



to extend into interior chamber 14 and adjacent to filter element 22. In this embodiment, capillary tube 48 provides a fluid conduit for liquid in entering region 28 to flow into interior region 40. Preferably the length and/or diameter of capillary tube 48 is selected to take advantage of the fluid pressure generated by the liquid flowing through filter assembly 10 and to induce a portion of the liquid to enter interior region 40 at a desired flowrate.

In one embodiment, capillary tube 48 extends from container 24 towards inlet 18 between casing 12 and filter element 22. In one preferred embodiment, capillary tube 48 extends the length of filter element 22. In other embodiments, the length of capillary tube 48 that extends beyond the exterior of container 24 is selected to be less than or equal to about three-fourths of the length of the filter element; or the length of capillary tube 48 is selected to be less than or equal to about one-half of the length of the filter element; still yet in another embodiment the length of capillary tube 48 is selected to be less than or equal to about one-fourth of the length of the filter element. The capillary tube end 49 can be provided in a variety of configurations including a round, oval, flattened configuration, or it can be configured to conform to the space between the exterior of the filter element and the interior of the housing.

Opposite end of capillary tube 48 can also extend into interior region 40. In the illustrated embodiment, capillary tube 48 extends adjacent to the lower wall portion or bottom of container 24. This prevents the incoming liquid from flowing directly across the top of container 24 toward exit port 44. It is preferable that the incoming liquid mix sufficiently with the additive contained within container 24. One method of promoting adequate mixing of the liquid and additive is to increase the period of time that the liquid remains in container 24 and/or increase the distance that the incoming liquid must flow in the interior region before exiting out exit port 44. It will be understood that in alternative embodiments capillary tube 48 need not extend to the bottom of container 24.

In the preferred embodiment, the difference in liquid density and the additive density can be utilized to achieve a more uniform release rate over time. (See below, FIG. 14.) Generally, the liquid additive is denser than the liquid flowing through the filter assembly (regardless whether the liquid is organic or aqueous based). Consequently, the filtered liquid tends to “float” on the additive phase, and the inlet tube is truncated near the top of the additive vessel, whereas the outlet capillary extends to near the bottom of the vessel. During operation, the liquid enters the inlet vessel, floats, and remains (largely, with exception of the slow diffusion between

phases) at the top of the vessel or layered on the liquid additive. As more of the liquid enters through the inlet vessel, the entering liquid displaces pure additive and pushing it out the outlet tube in nearly full-concentration yielding a very steady injection of active ingredient into the system.

5 Exit port 44 is provided in an upper wall portion of exterior wall 34 and is spaced apart from entrance port 42. Furthermore, in the illustrated embodiment, exit port 44 is centrally positioned in exterior wall 34 to extend centrally into interior region 40. However, it will be understood that exit port 44 can be positioned as desired in exterior wall 34 to extend into and/or through any portion of container 24. As illustrated in FIG. 1, exit port 44 can be defined by a  
10 capillary tube 54 extending into interior region 40. Capillary tube 54 provides a conduit between interior region 40 and interior chamber 14.

In one embodiment, capillary tube 54 provides fluid communication between the liquid and an additive initially located in interior region 40 and entering region 28. From entering region 28, liquid can then flow through filter element 22 and into exiting region 30. From there,  
15 the liquid can then flow through outlet 20 and back into the system--either a recirculating fuel, coolant, oil, or lubricant system or a single-pass fuel system.

In an alternative embodiment (see FIG. 14), capillary tube 54 provides an exit for the liquid and additive in interior region 40 to flow to exiting region 30. In this embodiment, capillary tube 54 provides direct fluid communication for a liquid and/or an additive mixture in  
20 interior region 40 and exiting region 30 and, ultimately, to outlet 20. Consequently, in this embodiment, the liquid and additive in interior region 40 can bypass filter element 22. This embodiment would offer a high gradient pressure, since the restriction of the filter element is now added to the dynamic pressure gradient ( $P_{dyn}$ ). This embodiment can provide particular advantages, for example, for injecting a very viscous additive into the system. Additionally, if  
25 desired a small filter, such as a sintered porous plug, wire-mesh screen, or the like, can be included on the outlet tube to prevent any large particles that have bypassed the filter from causing damage to downstream components.

Optionally, entrance port 42 and/or exit port 44 can be sealed with a soluble seal 43 and 45, respectively. This allows filter assembly 10 to be storage stable, and in particular, this can  
30 inhibit loss of activity and/or volume of the additive in container 24. In use, a liquid flowing through filter assembly 10 dissolves the seal material, allowing the liquid to enter into interior

region 40 and mix with the additive therein. Alternatively, the soluble seal can be composed of a low melting material that melts when exposed to the normal operating temperatures of the fuel flowing through the filter.

In one embodiment when the liquid is an organic base fluid such as fuel, oil or a lubricant, the soluble seal is composed of a material soluble in organic solvents.

Optionally, a separate second container illustrated as pre-charge chamber 56 can be included in filter assembly 10. In the illustrated embodiment, pre-charge chamber 56 is positioned in or on container 24. Pre-charge chamber 56 is a separate chamber, separated from the interior region 40 (and the liquid additive 25 therein) by partition 57. One end 58 of chamber 56 can be open or alternatively end 58 can be covered with a mesh or other porous structure. An additive 59 can be deposited into pre-charge chamber 56 and made available for immediate release into the liquid flowing through filter assembly 10. Additive 59 can be the same or different from additive 25.

The liquid additive 25 can be selected from any known and commercially useful composition that can provide beneficial properties to the particular liquid being filtered. The additive can be a liquid at ambient temperature or a solid component that has been dissolved in a suitable solvent. Examples of suitable fuel additives for use in the present invention include but are not restricted to lubricity aids, ignition promoters, and the like. Specific examples of lubricity aids include: alcohols, monohydroxy alkanols such as saturated aliphatic monohydric alcohols having from 1 to 5 carbon atoms, methanol, ethanol, propanol, n-butanol, isobutanol, amyl alcohol and isoamyl alcohol; monocarboxylic acids either saturated or unsaturated fatty acids, such as, caprylic acid, pelargonic acid, capric acid, undecylic acid, lauric acid, tridecoic acid, myristic acid, stearic acid, linoleic acid hypogeic acid, oleic acid, elaidic acid, erucic acid, brassidic acid; organo nitrates, such as, methyl nitrate ethyl nitrate, n-propyl nitrate, isopropyl nitrate, allyl nitrate, n-butyl nitrate, isobutyl nitrate, sec-butyl nitrate, tert-butyl nitrate, n-amyl nitrate, isoamyl nitrate, 2-amyl nitrate, 3-amyl nitrate, tert-amyl nitrate, n-hexyl nitrate, 2-ethylhexyl nitrate, n-heptyl nitrate, sec-heptyl nitrate, n-octyl nitrate, sec-octyl nitrate, n-nonyl nitrate, n-decyl nitrate, cyclopentyl nitrate, cyclohexyl nitrate, methylcyclohexyl nitrate, isopropylcyclohexyl nitrate and the like. Examples of these fuel additives can be found in U.S. Patent Nos. 4,248,182, 5,484,462, 5,490,864, and 6,051,039, each of which is incorporated herein by reference in its entirety. Furthermore, it should be understood that the term "fuel" as

used herein includes diesel, gasoline, kerosene, or other petroleum distillates. Consequently, the additive can be selected to provide a benefit to any of these different fuel compositions.

Additionally, the filter assemblies as described herein can be used with fuel delivery systems for combustion engines, including both diesel and gasoline engines, and/or for any other fuel storage and delivery device or system which may or may not be directly connected to a combustion engine.

The additives for coolants, lubricants, and oil can also be included in either the interior region 40 and/or the pre-charge chamber 56.

Examples of aqueous coolant additives that can be used in the present invention include one of more of the following without limitation: anticorrosion additives such as neutralized dicarboxylic acids, mercaptobenzothiazole, benzotriazole, tolyltriazole, and salts of molybdate, nitrite, nitrate, and silicate (preferably with ammonium, tetraalkyl ammonium, or alkali metal as the counter ion); and buffering agents which can be selected from any known or commonly used buffering agents, such as, borate salts and phosphate salts; as well as a variety of other additives, including defoamers, scale inhibitors, surfactants, detergents, and dyes. Examples of defoamers include components (alone or in combination) such as silicon defoamers, alcohols such as polyethoxylated glycol, polypropoxylated glycol or acetylenic glycols. Examples of scale inhibitors include components, either alone or in combination, such as, for example, phosphate esters, phosphino carboxylate, polyacrylates, polymethacrylate, styrene-maleic anhydride, sulfonates, maleic anhydride co-polymer, acrylate-sulfonate co-polymer and the like. Surfactants for use in this invention include, for example, either alone or in combination: Alkyl sulfonates, acryl sulfonates, phosphate esters, sulfosuccinate, acetylenic glycol, and ethoxylated alcohols. Detergents include non-ionic and/or anionic components such as, for example, phosphate ester surfactants, sodium alkyl sulfonates, sodium aryl sulfonates, sodium alkyl aryl sulfonates, linear alkyl benzene sulfonates, alkylphenols, ethoxylated alcohols, carboxylic esters, and the like. Examples of the coolant additives are discussed in U.S. Patent. No. 4,717,495, published US Patent application 20030042208, and pending US Patent applications 09/611,332 and 09/611,413 both filed on July 6, 2000, all of which are hereby incorporated by reference.

Additives for lubricants and oils are discussed in WO 03/018163, which is incorporated by reference herein. Examples include: are not limited to, one or more viscosity index improvers, antioxidants (also known as oxidation inhibitors), antiwear agents; and detergents.

Specific examples include: detergents, such as, sodium, barium, calcium or magnesium salts of salicylate esters, sulfonates, phosphonates, phenates, thiophosphonates; alkoxides, or carboxylates; dispersants, such as, long-chain and/or high molecular-weight ashless organic molecules, such as N substituted alkenyl succinimides, esters and polyesters, amine and polyamine salts of organic acids, Mannich bases derived from alkylated phenols, copolymers of methacrylates or acrylates, ethylene, propylene copolymers containing polar groups or vinyl acetate fumaric acid ester copolymers; antioxidants, such as, zinc dialkyl or diaryl dithiophosphates, phenolic compounds, organic phosphites, metal dithiocarbamates, sulfurized olefins, hindered or aromatic amines, organic selenides, phosphorized or sulfurized terpenes; corrosion inhibitors, such as, zinc dithiophosphates, organic phosphates, metal dithiocarbamates, phosphorized or sulfurized terpenes, sulfurized olefins, aromatic nitrogen compounds, sulfonates, alkenyl succinic acids, propoxylated or ethoxylated alkyl phenols, substituted imidazoles, barium, calcium or magnesium salts of oxides or carbonates; antiwear additives, such as, zinc, calcium, magnesium, nickel, cadmium or tetralkyl ammonium salts of dithiophosphoric, various molybdenum sulfur compounds, organic phosphites, sulfurized olefins, various triazoles, fatty acid derivatives, dicarbamate derivatives, and alkaline compounds as acid neutralizers; viscosity index improvers, such as, high molecular-weight polymers, for example olefin copolymers, ethylene-propylene copolymers, and polyisobutylenes, various styrene copolymers, for example, styrene and butadiene or isoprene; pour point depressants, such as, alkylated naphthalene, polymethacrylates, crosslinked alkylated phenols, vinyl acetate, fumaric acid ester copolymers, alkyl fumarate, vinyl ester copolymers, styrene-ester copolymers, derivatized alkyl methacrylate/acrylate copolymers, olefin copolymers, alkylated polystyrene; antifoamants, such as, silicones, polyethers; emulsifiers, such as, metal salts of carboxylic acids to name a few examples.

In use, the liquid to be filtered flows in through one or more of inlets 18 in nut plate 16, and from there into interior chamber 14. In the illustrated embodiment, a liquid flows into entering region 28 in the direction indicated by inflow arrows 60. It has been observed that the liquid flowing through a filter such as filter assembly 10 illustrated in FIGS. 1 through 3 exhibits a dynamic fluid pressure gradient within the interior chamber.

FIG. 4 is a graph illustrating the dynamic fluid pressure predicted by a computational fluid dynamics (CFD) model at varying axial positions within a filter [all points taken at radial

position midway in gap between filter shell ID (12) filter element pleat OD (22)]. The graph indicates that the fluid dynamic pressure is greatest near the top of the filter element endcap 31 where the axial velocity is highest. The dynamic pressure below the top endcap begins to diminish since the axial velocity decreases as fluid is carried inward through the filter. The y-axis on the graph is the CFD-predicted dynamic fluid pressure, in Kpa. The x-axis corresponds to the axial position in the filter measured with respect to the filter element at which the dynamic fluid pressure was reported via CFD. In the graph illustrated in FIG. 4, the bottom endcap of the filter element is at 0.1m and the top is at ~0.225m. The absolute value of the dynamic fluid pressure within the filter can vary depending upon a variety of factors that affect flow velocity in the gap between filter and housing, including: the overall length of the filter housing and/or filter element, the size of gap (annulus area) between the filter element and housing shell, the overall length of the filter housing and/or filter element, the configuration of the filter element (number of pleats, outer diameter of pleats, inner diameter of pleats, media thickness), the flowrate or volume of flowing through the filter casing and/or filter element, and the density of the flowing liquid. The dynamic pressure, Pdyn, can be calculated according to Equation 1:

$$P_{dyn} = 1/2 \times \text{density} \times \text{velocity}^2 \quad (1)$$

where density is the liquid density and velocity is the velocity of the liquid flowing through the filter.

The present invention takes advantage of this observation by positioning entrance port 42 where Pdyn is at a relatively high pressure and locating exit port 44 in an area within the interior chamber that exhibits lower fluid pressure. Since the entrance port is aligned perpendicular with the direction of flow (like a pitot tube), a stagnation zone forms in front of the tube causing the dynamic pressure to be converted to a static pressure which is harnessed to drive flow slowly into the tube and through the vessel.

In the illustrated embodiment, entrance port 42 is defined by the open terminal end of capillary tube 48. Capillary tube 48 extends from interior region 40 through wall 34 and up between filter element 22 and the interior wall of outer casing 12. Placing the entrance port 42 at the terminus of capillary tube 48 in an area of relatively high fluid pressure induces the liquid flowing through the liquid filter to enter interior region 40. In interior region 40, the liquid can mix with the liquid additive. Thereafter, the liquid and additive mixture can exit through exit port 44.

In one embodiment, exit port 44, as noted above, allows the liquid and additive mixture to re-enter the entering region 28 albeit in an area where the dynamic fluid pressure is less than the pressure in the area adjacent entrance 42 to capillary tube 48. In this embodiment, the liquid and additive mixture from the interior region 40 flows through the filter element 22 before exiting the filter assembly through outlet 20.

In an alternative embodiment, exit port 44 provides direct fluid communication between interior region 40 and exiting region 30. This allows the liquid and additive mixture from the interior region 40 to exit into exiting region 30 and from there be mixed with the bulk liquid in exiting region 30 into the fuel conduit (not shown) without passing through filter element 22.

Providing entrance port 42 in an area of relatively high fluid pressure and positioning exit port 44 in an area of lower fluid pressure provides substantial benefits for adding additives to flowing liquid. The release rate of a liquid additive in container 24 can be tailored as described. In one preferred embodiment, the desired release rate remains relatively constant over a long time period. This effect can be modified by varying the initial viscosity of the liquid additive in container 24. For example, if the initial viscosity of the liquid additive is substantially higher than that of the liquid flowing through filter assembly 10, then as the liquid begins to mix with and dilute the additive in the interior of container 24, the initial viscosity of the liquid and additive mixture slowly begins to decrease. The high viscosity inhibits rapid initial release of additive from container 24 due to the controlling restriction provided by the outlet capillary tube. The inlet capillary tube may also have a restriction, but since the liquid viscosity is much lower than that of the additive and the inlet tube is filled only with the liquid, the outlet capillary restriction largely controls/sets the flowrate that results from the fixed gradient pressure. However, over time, the relative amount of liquid in the liquid and additive mixture in container 24 increases. As the relative amount of the liquid component in the liquid and additive mixture increases, the viscosity of the resulting liquid and additive mixture decreases. The resulting decrease in viscosity causes the outlet capillary tube restriction to decrease which leads to corresponding increase in flowrate (of diluted fuel/additive mix), hence giving a more stable release of actual active ingredient (additive). At a given pressure gradient, the flowrate through the additive vessel having two capillary tubes in series (an inlet and an outlet) with differing viscosity in each tube (and neglecting any contribution of viscous drag offered by the vessel) can be modeled according to the following Equation 2:

$$Q = \frac{P\pi D_2^4 D_1^4}{128(\mu_2 L_2 D_1^4 + \mu_1 L_1 D_2^4)} \quad (2)$$

where Q = flowrate, P = gradient pressure, D<sub>2</sub> = inlet tube diameter, D<sub>1</sub> = outlet tube diameter, μ<sub>2</sub> = additive viscosity, L<sub>2</sub> = outlet tube length, L<sub>1</sub> = inlet tube length, and μ<sub>1</sub> = liquid viscosity. According to Equation 2, the desired flowrate can be easily adjusted by varying the tube geometries--especially the tube diameters, D<sub>1</sub> and D<sub>2</sub>, since flow varies inversely with the tube diameters to the fourth power. In use, the additive viscosity μ<sub>2</sub> will slowly decrease and the flowrate will increase. This effect will be more pronounced if the outlet tube provides the largest restriction to flow, for example, if D<sub>2</sub> were small. It has been determined that it is typical to achieve a ~three-fold increase in flow over the life of the filter/additive vessel when working with a ten-fold additive/fuel viscosity ratio. This three-fold increase in flow helps to counteract the decreasing active ingredient release rate due to the exponentially decaying concentration of active ingredient in the vessel.

FIGS. 5 and 6 are graphs which illustrate this effect for two cases where all other factors are equal, including additive vessel volume and total additive released in a 300-hour period. Only the inlet tube diameter is adjusted to achieve the correct total additive release. The first graph in FIG. 5 shows how the flowrate is constant for the case of a vessel that lacks an outlet capillary (since inlet pressure is constant and viscosity in the inlet tube is constant). When a capillary tube is added to outlet of the container, the initial flowrate is reduced--but the final flowrate has increased almost three-fold due to declining viscosity.

The graph illustrated in FIG. 6 shows the “active ingredient” or additive injection rate for these same two cases. When the container does not include a capillary tube outlet, an exponential decay (about 80% decrease in this case) in the release rate of the additive is anticipated. When the container contains a capillary tube outlet, the injection rate curve is significantly flattened (~50% decrease in the release rate of the additive) due to the rising flowrate offsetting the decreasing additive concentration of the diluted vessel mixture. For both cases, the total amount of additive released in the 300-hour time period is about equal. However, the case where the container includes a capillary outlet tube will provide better protection to the fuel system since the release rate of the additive is more constant.

In addition, the rate that liquid enters into container 24 can be varied. Increasing the pressure differential between entrance port 42 of exit port 44 will induce a more rapid in-flow



and escape of the liquid and additive mixture from the interior region 40 of container 24. Extending end 49 of capillary tube 48 closer to inlet 18 can increase the dynamic pressure. Similarly, end 55 of capillary tube 54 in an area at lower pressure such that proximate to exiting region 30 can decrease the dynamic fluid pressure at exit port 44.

5 In another embodiment, varying the configuration and/or size of capillary tube 48 and/or capillary tube 54 can vary the pressure difference between the fluid entering and exiting container 24. For example, the diameter of one or both of capillary tubes 48 and 54 can be varied.

10 Conversely, placing entrance port 42 and exit port 44 such that the relative pressure differential between the two is small provides for a low flowrate through container 24.

FIG. 7 is a partial view in full section of an alternative embodiment of filter assembly 70 in accordance with the present invention. Filter assembly 70 is formed similarly to filter assembly 10. Consequently, like reference numbers will be used to denote like components.

15 Filter assembly 70 includes an outer casing 12 defining an interior chamber 14. A filter element 22 and container 72 are provided in the interior chamber. Container 72 contains a liquid fuel additive 74. Container 72 includes an exterior wall 76, an entrance port 78, and an exit port 80. In the illustrated embodiment, entrance port 78 is provided substantially as has been described for entrance port 42 and can include capillary tube 82. Opening 84 defines exit port 80. Opening 84 can be provided as a substantially small diameter opening or a capillary-sized opening. Opening 84 provides direct fluid communication between interior chamber 14 and interior region 73. In one embodiment, opening 84 can open directly into entering region 28 by locating opening 84 in a portion of exterior wall adjacent entering region 28, such as a position diametrically opposite that of capillary tube 82. Alternatively, opening 84 can open directly into exiting region 30 by locating opening 84 adjacent the exiting region.

25 FIG. 8 is a partial view with sections broken away of yet another embodiment of filter assembly 90 in accordance with the present invention. Filter assembly 90 is provided similarly as filter assembly 70 and filter assembly 10. Consequently, like reference numbers will be used to denote like components. Filter assembly 90 includes container 92 positioned in interior chamber 14. Container 92 includes exterior wall 94 defining interior region 96. Entrance port 98 and exit port 100 extend through exterior wall 94. Entrance port 98 can be provided substantially as described above for entrance port 42 including capillary tube 48 and/or entrance

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port 78 (and capillary tube 82), and exit port 100 can be provided substantially as has been described for exit port 44 including capillary tube 54 and/or exit port 80.

Container 92 also includes one or more interior partitions 102 defining a fluid pathway or channel 104 coursing through the interior region 96.

FIG. 9 is a sectional view of the container illustrated in FIG. 5 taken along section line 9-9. It can be seen in the illustration that container 92 contains a partition 102 provided substantially as a spiral wall 106 that defines a curving pathway 108 coursing through interior region 96. In a preferred embodiment, partition 102 is provided as a solid portion or wall portion extending the full depth of container 92, i.e., from the upper surface 110 to the lower surface 112. In other embodiments, partition 102 need not extend the full depth of container 92 but may be attached to either upper surface 110 or lower surface 112 or even as an unattached or secure insert within the interior of container 92. In still other embodiments, partition 102 need not be a solid wall or an imperforate structure but can include openings and/or voids.

In the illustrated embodiment, the liquid enters through port 98 and mixes with the liquid additive that is contained within container 92. Consequently, the liquid and additive mixture must course its way through the channel 104 defined by partition 102 before the mixture can exit through port 100.

FIG. 10 is a cross-sectional view of another embodiment of a filter assembly 114 in accordance with the present invention. Filter assembly 114 is provided similarly as filter assemblies 90, 70, and 10; consequently similar reference numbers will be used to refer to similar components. Filter assembly 114 includes a container 115 defining an interior region 40 for an additive.

Container 115 includes a first capillary tube 116 defining an inlet and an outlet 122 that provides an opening directly downstream of the filter element. Outlet 122 can include a capillary tube 123 that extends upwardly through a second container 127 or a reservoir region. Consequently, capillary tube 123 can provide a dam to inhibit inadvertent introduction of a secondary additive from the second container 127 into the container 115. In one embodiment, capillary tube 123 is molded directly into the upper wall 129 of the first container 115.

Referring additionally to FIG. 11, it can be seen that the first capillary tube 116 is located proximate to the internal wall portion 118 of container 115. In this embodiment, outlet 122 is

centrally located in the upper wall 129 of container 115 and therefore spaced from first capillary tube 116.

FIGS. 12 and 13 illustrate one embodiment of a replaceable cartridge 126 for use in the present invention. Replaceable cartridge 126 can be provided substantially as has been described for containers 115, 92, 72, and/or 24. Consequently, like reference numbers will be used to denote like components. Replaceable cartridge 126 includes an exterior wall 34 having an entrance port 42 and an exit port 44. Replaceable cartridge 126 provides the added advantage in that it can be readily placed in existing filters and/or replaced when the additive contained in the interior chamber has been exhausted. In the illustrated embodiment, cartridge 126 does not include any inserts to direct fluid flow therethrough. However, it will be understood that any of the inserts described above can be included inside container 126 as desired. Such assemblies are intended to be included within the scope of the present invention.

FIG. 14 is a cross-sectional view of yet another embodiment of a filter assembly 130 prepared in accordance with the present invention. Filter assembly 130 can be provided substantially as has been described for filter assemblies 10, 70, and 90. Consequently, like reference numbers will be used to denote like components. Filter assembly 130 includes container 134 axially spaced from a filter element 132 in interior chamber 133. In this embodiment, it can be observed that container 134 can be provided substantially as described above for any of containers 24, 72, 92, and 126. Container 134 can be a removable cartridge if desired. For example, container 134 can be removed from the interior region simply by separating lower housing 138 from an upper housing or nut plate 140. After lower housing 138 has been separated from upper housing 140, either one or both of filter element 132 and/or container 134 can be replaced and/or refurbished. For example, container 134 can be replaced with a new container or cartridge filled with an additive. Alternatively, existing container 134 be refilled with a fresh charge of an additive.

Capillary tube 136 defines an inlet into the interior region 138 of container 134. It can be observed from the illustration that capillary tube 136 extends substantially the full length of filter element 132. However, capillary tube 136 only extends a short distance through the upper wall portion inside container 134. The terminus of capillary tube 136 can include one or more of a seal, such as a seal (soluble in the liquid flowing through the filter, either a fuel, lubricant, oil, or coolant), a filter element, or a porous or other mesh covering as discussed above.

Capillary tube 140 defines an outlet port 142 from container 134. Capillary tube 140 extends up into the exiting region 30. Optionally capillary tube 140 can include one or more of a seal, such as a soluble seal, a filter element or a porous or other mesh covering 141 over its terminus. The opposite end of capillary tube 140 extends nearly to the lower wall portion or bottom of container 134.

In this embodiment, the liquid enters container 134 through capillary tube 140. Since the liquid typically is less dense than the additive in container 134, the liquid will first layer on top of the additive and force substantially pure additive out through capillary tube 140 and into the portion of the liquid flowing through the exiting region 30.

In the preferred embodiment, the difference in liquid density and the additive density can be utilized to achieve a more uniform release rate over time. Since the liquid is less dense than the liquid additive, the liquid tends to “float” on the additive phase and the inlet tube is truncated near the top of the additive vessel, whereas the outlet capillary extends to near the bottom of the vessel. During operation, as the liquid enters the inlet vessel and floats and remains (largely, with exception of the slow diffusion between phases) on the top of the vessel, displacing pure additive and pushing it out the outlet tube in nearly full-concentration yielding a very steady injection of active ingredient into system.

FIG. 15 is still yet another embodiment of a filter assembly 150. Filter assembly 150 can be provided substantially as has been described for filter assemblies 10, 70, 90 and 130.

Consequently, like reference numbers will be used to denote like components. Filter assembly 150 includes a container 152 in an interior chamber 154. Capillary tube 156 provides an inlet into the interior region 158 of container 152. In this embodiment, capillary tube 156 extends in a direction parallel to and substantially along the entire length of filter element 22. Upper endcap 158, shown in an enlarged view in FIG. 16, includes a shroud 160 that extends downwardly and in a radially direction toward the upper end 162 of capillary tube 156.

In this embodiment, the endcap shroud 161 cooperates with filter shell 164 to somewhat constrict the flow and hence increase the velocity in close proximity to entrance of capillary tube 158. This in turn increases the dynamic fluid pressure at end 162. Consequently, the pressure difference between the entrance and exit from container 152 is greater than would be observed if the fuel were not constricted between filter endcap shroud and shell.

The present invention provides distinct advantages to delivery systems. The use of a liquid additive in the container allows the maximum amount of an additive to be included within a filter assembly because the liquid additive can completely fill the internal volume of the container where as solid additives do not. Furthermore, by harnessing the pressure gradient generated within a filter assembly in use, the rate of addition of the additive is much more independent of vibration variation that may occur during use. However, the rate of release of the additive as noted above can be adjustable by varying the length and/or diameters of the capillary tubes leading into and out of the container holding the fuel additive.

The present invention also provides a method of adding beneficial additives to the liquid only with the liquid flowing through the filter. When the liquid is not flowing through the filter, diffusion of any additive out of the container has been measured to be negligible because of the extremely low molecular diffusion rate. The molecular diffusion rate is described by the binary diffusion coefficient, which in the above-described embodiments with the liquid/additive is on the order of  $2e^{-6} \text{ cm}^2/\text{s}$  between the additive and the liquid phases, and the dynamic fluid pressure gradient is zero when there is no flow so convective transfer is also eliminated.

The present invention also contemplates modifications as would occur to those skilled in the art. It is also contemplated that the devices and processes embodied in the present invention can be altered, rearranged, substituted, combined, or added to other processes as would occur to those skilled in the art without departing from the spirit of the present invention. All patents and patent applications cited in this specification are herein incorporated by reference as if each individual patent or patent application was specifically and individually indicated to be incorporated by reference and set forth in its entirety herein.

Any reference to specific directions, for example, references to up, upper, down, lower, on top of, below, and the like, is to be understood for illustrative purposes only or to better identify or distinguish various components from one another. These references are not to be construed as limiting in any manner to the devices, methods, and/or operations as described herein.

Unless specifically identified to the contrary, all terms used herein are used to include their normal and customary meaning.

Further, while various embodiments of filter assemblies having specific components and structures are described and/or illustrated in the Figures herein, it is to be understood that any

selected embodiment of a filter assembly can include one or more of the specific components and/or structures described for other embodiments where possible.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is considered to be illustrative and not restrictive in character. It is understood that only the preferred embodiments have been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

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